RATIO AND RATE EFFECTS OF ^{32}P-TRIPLE SUPERPHOSPHATE AND PHOSPHATE ROCK MIXTURES ON CORN GROWTH

Vinícius Ide Franzini[1]; Takashi Muraoka[2]*; Fernanda Latanze Mendes[1]

[1] *USP/ESALQ - Programa de Pós-Graduação em Solos e Nutrição de Plantas, C.P.09 - 13418-900 - Piracicaba, SP - Brasil.*
[2] *USP/CENA - Lab. de Fertilidade do Solo, C.P.96 - 13400-970 - Piracicaba, SP - Brasil.*
**Corresponding author <muraoka@cena.usp.br>*

ABSTRACT: The availability of phosphorus (P) from "Patos de Minas" phosphate rock (PR) can be improved if it is applied mixed with a water-soluble P source. The objective of this study was to evaluate ^{32}P as a tracer to quantify the effect of the ratio of mixtures of triple superphosphate (TSP) with PR and the rates of application on P availability from PR. Two experiments were conducted in a greenhouse utilizing corn (*Zea mays* L.) plants as test crop. In the first experiment, the P sources were applied at the rate of 90 mg P kg^{-1} soil either separately or as compacted mixtures in several TSP:PR ratios (100:0, 80:20, 60:40, 50:50, 40:60, 20:80 and 0:100 calculated on the basis of the total P content). In the second experiment, the TSP was applied alone or as 50:50 compacted mixtures with PR applied at four P rates (15, 30, 60 and 90 mg P kg^{-1}) while the sole PR treatment was applied at the 90 mg kg^{-1} P rate . The mixture of PR with TSP improved the P recovery from PR in the corn plant and this effect increased proportionally to the TSP amounts in the mixture. When compared with the plant P recovery from TSP (10.52%), PR-P recovery (2.57%) was much lower even when mixed together in the ratio of 80% TSP: 20% PR. There was no difference in PR-P utilization by the corn plants with increasing P rates in the mixture (1:1 proportion). Therefore, PR-P availability is affected by the proportions of the mixtures with water soluble P, but not by P rates.
Key words: Typic Haplustox, relative agronomic effectiveness, phosphorus recovery, radioisotope

PROPORÇÕES E DOSES DAS MISTURAS DE ^{32}P-SUPERFOSFATO TRIPLO COM FOSFATO NATURAL NO DESENVOLVIMENTO DO MILHO

RESUMO: A disponibilidade de fósforo do fosfato natural de Patos de Minas (FN) pode ser melhorada se aplicado junto com uma fonte de P solúvel em água. O objetivo desse estudo foi usar o ^{32}P como traçador para quantificar o efeito das doses e das proporções das misturas de superfosfato triplo (SFT) com FN no aumento da disponibilidade de P do FN. Dois experimentos foram desenvolvidos em casa-de-vegetação com plantas de milho (*Zea mays* L.) como cultura teste. No primeiro experimento as fontes de fósforo, na dose de 90 mg kg^{-1} de P, foram aplicadas sozinhas ou em misturas compactadas e em várias proporções de SFT com FN (80:20, 60:40, 50:50, 40:60 e 20:80) calculadas com base no teor de P total, enquanto que no segundo, o superfosfato triplo foi aplicado tanto sozinho como em misturas compactadas com o fosfato natural de Patos e em quatro doses de P (15, 30, 60 e 90 mg kg^{-1}) na proporção de 50:50 e o FN sozinho na dose de 90 mg P kg^{-1}. A mistura do FN com o SFT melhorou o aproveitamento do P do FN pelo milho e esse efeito foi crescente com o aumento da proporção do SFT na mistura. Se comparado com o aproveitamento do P do SFT (10,52%) pelas plantas o aproveitamento do P do FN (2,57%) foi baixo, mesmo na proporção de 80% SFT: 20% FN. Não houve diferença no aproveitamento do P do PR entre as doses da mistura na proporção de 1:1. Portanto, a disponibilidade de P do FN é afetada pela proporção das misturas com a fonte solúvel de P, mas não pelas doses deste nutriente.
Palavras-chave: Latossolo Vermelho Amarelo, eficiência relativa agronômica, aproveitamento de P, radioisótopo

INTRODUCTION

Phosphorus (P) deficiency is a major constraint to crop production in most tropical and subtropical acid soils, and P fertilizers are required to sustain optimum crop yields (Zapata & Zaharah, 2002).

Although direct application of phosphate rock (PR) is an interesting low-cost option for supplying P, PRs with low to medium reactivity usually do not give promising results comparable to soluble P fertilizers in terms of annual crops yield response (Hammond et al., 1986; Chien & Friesen, 1992; Chien & Menon, 1995).

Supplying a crop the early P requirements with water-soluble P mixed with PR has been shown to be more effective for early root development than applying only PR as fertilizer (Chien et al., 1996). Additionally, the acidity generated from the hydrolysis of superphosphates in the soil would solubilize the PR and thereby increase P availability from PR (Mokwunye & Chien, 1980). This practice has given positive agronomic results with increase in P utilization from PR by plants (Zapata & Zaharah, 2002; Prochnow et al., 2004). However, Xiong et al. (1996), using ^{32}P-labeled single superphosphate, did not find the same effect for a low reactive PR from China.

Most of the studies on mixtures of water-soluble P fertilizers and PRs used the 50:50 ratio (Zapata & Zaharah, 2002; Prochnow et al., 2004), and the effect of the ratio of the components on PR-P availability has not been widely reported. The use of ^{32}P as a radiotracer is essential to distinguish P availability from soil P, PR, or water-soluble P, because of possible interactions among water-soluble P, PR, and soil P (Chien et al., 1996).

The objective of this greenhouse study was to use ^{32}P as a tracer to quantitatively evaluate the effect of different ratios of TSP and PR ratios and P application rates on P recovery from PR by corn grown in a Typic Haplustox.

MATERIAL AND METHODS

Two experiments were conducted in the greenhouse conditions utilizing corn plants (*Zea mays* L.) as the test crop. The experimental design consisted of randomized complete blocks with four replications. The soil material used was from a dystrophic Typic Haplustox (Latossolo Vermelho-Amarelo distrófico, according to the Brazilian classification) collected from the 0.0–0.2 m depth in Piracicaba (22º42’ S, 47º38’ W), São Paulo State, Brazil. The soil sample was air dried, homogenized and sieved through a 4 mm screen for the pot experiments, and 2 mm screen for laboratory analysis. The soil material was limed according to Raij et al. (1996), to reach 70% base saturation and incubated for 30 days prior to the beginning of experiment, maintaining the moisture content at approximately 70% of the field capacity.

The P sources used were triple superphosphate (TSP) and powdered Patos de Minas (Brazil) phosphate rock (PR). The first experiment comprised the application of these P sources either alone or in compacted mixtures in the following TSP:PR ratios: 80:20, 60:40, 50:50, 40:60 and 20:80 based on total P of these sources, at the rate of 90 mg P kg^{-1}. In the second experiment, the P rates were 0, 15, 30, 60 and 90 mg kg^{-1} as TSP either alone or mixed and compacted with PR in a 50:50 ratio (7.5 TSP + 7.5 PR, 15 TSP + 15 PR, 30 TSP + 30 PR, 45 TSP + 45 PR) and also sole PR applied at the rate of 90 mg P kg^{-1}. A control (without P fertilizer) treatment, where only the carrier-free ^{32}P solution was applied to the soil, with an activity of 7.4 MBq per pot, was set as the reference for the isotopic method.

The TSP fertilizer was finely ground (0.15 mm or 100 mesh), moistened with deionized water, oven-dried at 90ºC and broken in pieces at approximately the same grain size as the original fertilizer. For the compacted mixtures, the PR and TSP, both finely ground (0.15 mm), were weighed for each ratio or P rate, moistened with deionized water and mixed, obtaining homogeneous compacted mixtures. After oven-drying at 90ºC, those mixtures were broken down into pieces of approximately the same grain size as the TSP fertilizer. The compacted mixtures of ^{32}P-TSP (55 KBq-^{32}P mg^{-1} of P) with PR were also similarly prepared.

The P sources were applied in a furrow at a depth ≈ 5 cm and covered with soil in the plastic pots lined with polyethylene bags and filled with 2.5 kg soil. Three corn (*Zea mays* L.) seeds (Pioneer 30F33 hybrid) were sown in each pot and thinned to one plant six days after germination. 150 mg kg^{-1} of N and K each were applied to each pot respectively as $(NH_4)_2SO_4$ and KCl. Ten mL of a micronutrients (B, Cu, Mn, Mo and Zn) solution (Sarruge, 1975) were also added to each pot. The pots were watered using deionized water to maintain soil moisture content at approximately 70% of field capacity.

The above-ground corn plants were harvested at 50 (ratio experiment) and 60 (P rates experiment) days after planting, oven-dried at 60ºC, weighed and ground using a Wiley mill. After digestion with nitric-perchloric acids, the ^{32}P activity was counted in a Liquid Scintillation counter by Cerenkov effect (Vose, 1980) with counts corrected for counting efficiency (Nascimento Filho & Lobão, 1977) and the total P concentration was determined by the Sarruge & Haag (1974) method.

The proportion (%) and amount (mg per pot) of P in the plants derived from soil, TSP, and PR were calculated according to the ^{32}P isotopic dilution method (Chien et al., 1996; Villanueva et al., 2006) as follows:

PR + Soil

$$F_{PR} = 1 - (SA_{P(PR+soil)} / SA_{P(soil)}) \quad (1)$$

$$P_{PR} = P_{(PR+soil)} F_{PR} \quad (2)$$

where F_{PR} = fraction of P uptake from PR; $SA_{P(PR+soil)}$ = specific activity of P uptake from (PR + soil); $SA_{P(soil)}$ = specific activity of P uptake from soil; P_{PR} = P uptake from phosphate rock; $P_{(PR+soil)}$ = P uptake from (PR + soil).

TSP + Soil

$$F_{TSP} = SA_{P(TSP+soil)} / SA_{F(TSP)} \quad (3)$$

$$P_{TSP} = P_{(TSP+soil)} F_{TSP} \quad (4)$$

$$P_{soil(TSP)} = P_{(TSP+soil)} - P_{TSP} \quad (5)$$

where F_{TSP} = fraction of P uptake from TSP; $SA_{P(TSP+soil)}$ = specific activity of P uptake from (TSP + soil); $SA_{F(TSP)}$ = specific activity of fertilizer TSP; $P_{(TSP+soil)}$ = P uptake from (TSP + soil); P_{TSP} = P uptake from TSP; $P_{soil(TSP)}$ = P uptake from soil in the presence of TSP.

PR + TSP + Soil

$$F_{TSP(PR)} = SA_{P(PR+TSP+soil)} / SA_{F(TSP)} \quad (6)$$

$$P_{TSP(PR)} = P_{(PR+TSP+soil)} F_{TSP(PR)} \quad (7)$$

$$P_{(PR+soil)(TSP)} = P_{(PR+TSP+soil)} - P_{TSP(PR)} \quad (8)$$

$$P_{PR(TSP)} = P_{(PR+soil)(TSP)} - P_{soil(PR+TSP)} \quad (9)$$

where $F_{TSP(PR)}$ = fraction of P uptake from TSP in the presence of PR; $SA_{P(PR+TSP+soil)}$ = specific activity of P uptake from (PR + TSP + soil); $SA_{F(TSP)}$ = specific activity of fertilizer TSP; $P_{TSP(PR)}$ = P uptake from TSP in the presence of PR; $P_{(PR+TSP+soil)}$ = P uptake from (PR + TSP + soil); $P_{(PR+soil)(TSP)}$ = P uptake from (PR + soil) in the presence of TSP; $P_{soil(PR+TSP)}$ = P uptake from soil in the presence of (PR + TSP); $P_{PR(TSP)}$ = P uptake from PR in the presence of TSP.

The coefficient of P utilization or P fertilizer recovery was also determined.

P Recovery

$$PRec(\%) = (P_{PDF} / P_{applied}) \times 100 \quad (10)$$

where P_{PDF} = amount of P uptake by plants from fertilizer (PR or TSP); $P_{applied}$ = amount of P applied in the soil.

The indices of relative agronomic effectiveness (RAE) were calculated based on the shoot dry weight and total P uptake.

RAE (%) (Relative agronomic effectiveness)

The RAE was calculated as:

$$RAE(\%) = [(Y_1 - Y_0) / (Y_2 - Y_0)] \times 100 \quad (11)$$

where Y_1 is the dry-matter yield or P uptake in PR or (TSP + PR) treatments; Y_2 is the dry-matter yield or P uptake in TSP treatment; Y_0 is the dry-matter yield in control treatment (without P added).

The data obtained were submitted to analysis of variance (F test), regression analysis and the treatment means differences were evaluated by the Tukey Range Test (p = 0.05) using the SAS package (SAS, 1996).

RESULTS AND DISCUSSION

Soil and P Fertilizers Characterization

The main soil chemical and physical properties determined according to standard analytical methods described by Camargo et al. (1986) and Raij et al. (2001) are pH ($CaCl_2$) = 4.7; OM = 20 g dm^{-3}; P (resin extractable) = 6 mg dm^{-3}; K, Ca, Mg, H+Al, SB and CEC, respectively 0.8, 12.9, 6.4, 31.2, 20.1 and 51.3 $mmol_c$ dm^{-3}; V= 39.2%; sand, silt and clay, respectively 650, 70 and 280 g kg^{-1}.

The fertilizers used presented the following characteristics: TSP = 19.2% total P; 19.0% P soluble in neutral ammonium citrate + water ($NAC+H_2O$); 17.1% P soluble in 2% citric acid (CA); 16.5% P soluble in water; PR = 10.5% total P; 0.7% $NAC+H_2O$ P; 1.8% P soluble in CA .

First experiment

All TSP treatments were superior in terms of dry-matter yield (Table 1) and P uptake (Table 2) as compared to the control one, thus indicating the soil

Table 1 - Above ground part dry-matter weight and relative agronomic effectiveness (RAE) obtained with TSP and PR sources mixed in different ratios for corn plants.

P source	Dry-matter yield	RAE
	g per pot	%
100% TSP	15.25 a	100
80% TSP + 20% PR	13.35 b	83
60% TSP + 40% PR	11.67 c	69
50% TSP + 50% PR	11.24 c	65
40% TSP + 60% PR	10.11 c	55
20% TSP + 80% PR	8.17 d	39
100% PR	4.91 e	10
Control	3.72 e	0

Dry matter yield values followed by different letters are different (p < 0.05), as determined by Tukey multiple range test.

Table 2 - Phosphorus uptake and relative agronomic effectiveness (RAE) obtained with TSP and PR sources mixed in different ratios for corn plants.

P source	P uptake	RAE
	mg per pot	%
100% TSP	26.19 a	100
80% TSP + 20% PR	20.17 b	71
60% TSP + 40% PR	16.23 c	52
50% TSP + 50% PR	13.70 cd	39
40% TSP + 60% PR	12.17 de	32
20% TSP + 80% PR	10.25 e	22
100% PR	7.17 f	7
Control	5.67 f	0

P uptake values followed by different letters are different ($p < 0.05$), as determined by Tukey multiple range test.

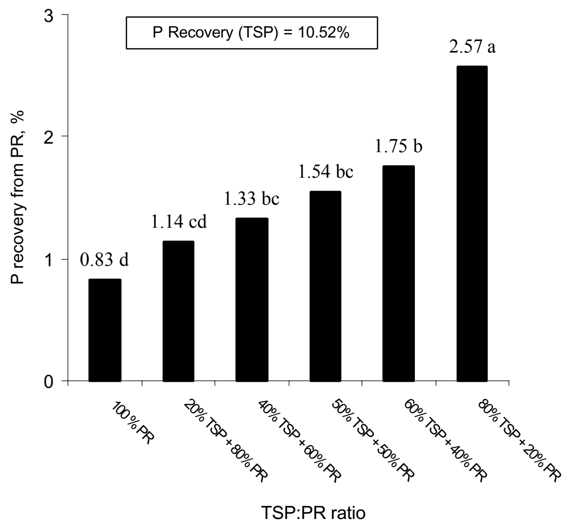

Figure 1 - Phosphorus fertilizer recovery by corn plants from "Patos de Minas" phosphate rock (PR) applied alone or in compacted mixtures with triple superphosphate (TSP + PR). Values followed by different letters are different ($p < 0.05$), as determined by the Tukey multiple range test.

low P availability. However, there were no differences in dry matter yield and P uptake between the control and 100% PR treatment, confirming the low agronomic effectiveness of the PR when applied alone .The low effectiveness of this P source in terms of dry matter yield and P uptake by plants was also observed in other studies with wheat, ryegrass and eucalyptus (Prochnow et al., 2004; Villanueva et al., 2006).

The values of relative agronomic effectiveness calculated based both on above ground part dry matter yield and total P uptake in the corn plants from P sources, showed the higher effectiveness of TSP fertilizer, while the PR was the least effective, as expected (Tables 1 and 2). The compacted mixtures had intermediate effectiveness, being higher with higher TSP ratio. In general, these results are similar to those reported by Nachtigall et al. (1989), who observed that increasing the ratio of TSP when mixed with Jacupiranga phosphate rock (another Brazilian low reactivity PR) in the same granule, increased the RAE. The calculated values of P recovery by corn plant from sole PR or mixtures of TSP + PR in several ratios are shown in Figure 1.The P utilization coefficient of the sole TSP (^{32}P-TSP) treatment by the corn plants was 10.5%, which was higher than the highest PR-P recovery (2.6%).

The addition of soluble P to PR increased the utilization of PR-P by the corn plants and this effect was enhanced with the increasing of the TSP proportion in the mixture (Figure 3) probably because more acidity was generated by the hydrolysis of the water-soluble P fertilizer. As the TSP and the PR were applied together, the enhancement effect was most likely due to chemical interaction between the P sources in the mixtures (Mokwunye & Chien, 1980). This increasing effect on the availability of PR-P when mixed with P sources of higher solubility was not observed by Nachtigall et al. (1989) and Xiong et al. (1996) with low reactivity PR from Brazil and China, respectively. The increasing uptake of the PR-P applied as dry compacted mixture with single superphosphate was estimated by a regression equation, compared to sole PR application to wheat and ryegrass (Prochnow et al., 2004).

Second experiment

The dry matter yield and P accumulation in the corn plants increased significantly with increasing P rates applied as TSP or TSP + PR (Figures 2 and 3). Although PR-P uptake by corn plants increased with P rate, the relative P recovery from TSP applied alone or as a 50:50 mixture with PR, decreased (Figure 4), because the P recovery is dependent on correlated with P rate applied.

The PR decreased P recovery from water-soluble P applied as TSP (Figure 4). For example, P recovery from TSP applied alone at the 30 mg kg^{-1} P rate was 10.6%, whereas P recovery from the same rate of TSP is mixture with PR (60 mg kg^{-1} P = 30 TSP + 30 PR) was 7.1%. This was probably due to the chemical interaction between the P sources in the mixtures that may result in the formation of water-insoluble iron phosphate (Fe-P) compounds as observed by Prochnow et al. (2003) in acidulated P fertilizers obtained from the Araxá phosphate rock.

No effects ($p > 0.05$) in P recovery from PR were found in response to P rate, but in all compacted mixtures of PR with TSP P recovery from PR was higher than sole applied PR (Table 3).

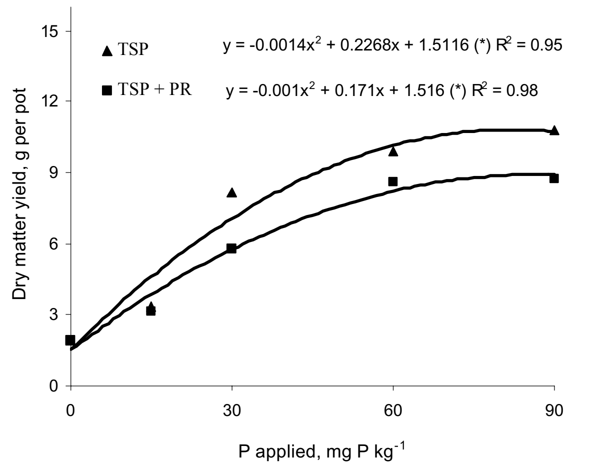

Figure 2 - Dry matter yield by corn plants treated with triple superphosphate (TSP) applied alone or in compacted mixtures with "Patos de Minas" phosphate rock (TSP + PR).

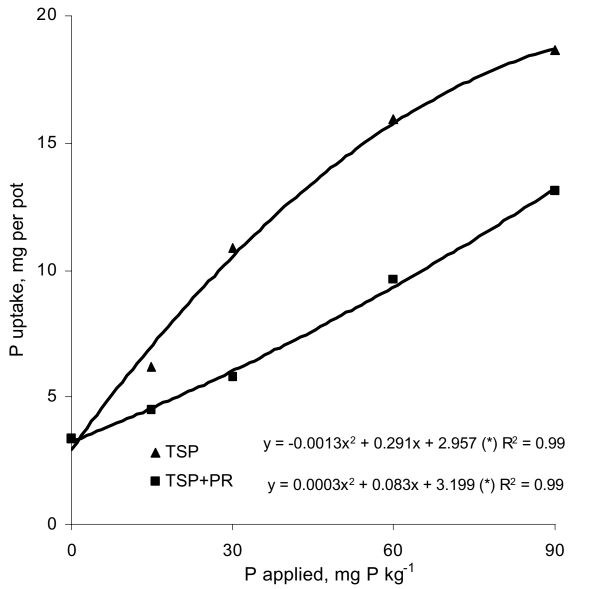

Figure 3 - Phosphorus uptake by corn plants treated with triple superphosphate (TSP) applied alone or in compacted mixtures with "Patos de Minas" phosphate rock (TSP + PR).

CONCLUSIONS

The enhancing effect of TSP on the effectiveness of the Patos PR is dependent on the TSP to PR proportion, increasing proportionally with the amounts of the water soluble P in the mixture. This effect was most likely due to chemical interaction between P sources in the mixture, which caused also reduction in P availability of the water soluble P source. The PR-P availability to corn plants did not increase with increasing mixture P rates.

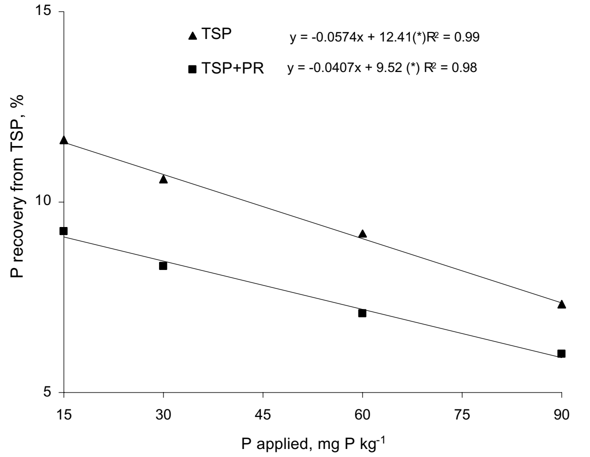

Figure 4 - Phosphorus fertilizer recovery by corn plants from triple superphosphate (TSP) applied sole or in 50:50 compacted mixtures with "Patos de Minas" phosphate rock (TSP+PR).

Table 3 - Phosphorus fertilizer recovery by corn plants from "Patos de Minas" phosphate rock (PR) applied sole or in compacted mixtures with triple superphosphate (TSP + PR) at ratio 50:50.

Treatments	P recovery from PR
mg P kg^{-1}	%
90 (PR)	0.54 b
15 (7.5 TSP + 7.5 PR)	1.66 a
30 (15 TSP + 15 PR)	1.61 a
60 (30 TSP + 30 PR)	1.95 a
90 (45 TSP + 45 PR)	1.96 a

Values for P recovery followed by different letters are different ($p < 0.05$), as determined by Tukey multiple range test.

ACKNOWLEDGEMENTS

To CAPES for the research scholarship granted to the first and third authors; to CNPq for the research fellowship to the second author and the FAPESP for financial support.

REFERENCES

CAMARGO, O.C.; MONIZ, A.C.; JORGE, J.A.; VALADARES, J.M.A.S. **Métodos de análise química, mineralógica e física de solos do Instituto Agronômico de Campinas.** Campinas: IAC, 1986. 94p. (Boletim Técnico, 116).

CHIEN, S.H.; FRIESEN, D.K. Phosphate rock for direct application. In: FUTURE DIRECTIONS FOR AGRICULTURAL PHOSPHORUS RESEARCH, Muscle Shoals, 1990. **Proceedings**. Muscle Shoals: International Fertilizer Development Center, 1992. p.47-52. (Bulletin, Y 224).

CHIEN, S.H.; MENON, R.G. Factors affecting the agronomic effectiveness of phosphate rock for direct application. **Fertilizer Research,** v.41, p.227-234, 1995.

CHIEN, S.H.; MENON, R.G.; BILLINGHAM, K.S. Phosphorus availability from phosphate rock as enhanced by water-soluble phosphorus. **Soil Science Society of America Journal,** v.60, p.1173-1177, 1996.

HAMMOND, L.L.; CHIEN, S.H.; ROY, A.H.; MOKWUNYE, A.U. Agronomic value of unacidulated and partially acidulated phosphate rocks indigenous to the tropics. **Advances in Agronomy**, v.40, p.89-140, 1986.

MOKWUNYE, A.U.; CHIEN, S.H. Reactions of partially acidulated phosphate rock with soils from the tropics. **Soil Science Society of America Journal,** v.44, p.477-482, 1980.

NACHTIGALL, G.R.; BRAUNER, J.L.; ZOLEZZI, M.; TAPIA, F. Mistura de superfosfato triplo com fosfato de Jacupiranga no mesmo grânulo na eficiência do fosfato natural. **Revista Brasileira de Ciência do Solo,** v.13, p.269-273, 1989.

NASCIMENTO FILHO, V.F.; LOBÃO, A.E. **Detecção de ^{32}P em amostras de origem animal e vegetal por efeito Cerenkov, cintilação líquida e detector GM**. Piracicaba: USP/CENA, 1977. (Boletim Científico, 48).

PROCHNOW, L.I.; CHIEN, S.H.; TAYLOR, R.W.; CARMONA, G.; HENAO, J.; DILLARD, E.F. Characterization and agronomic evaluation of single superphosphates varying in iron phosphate impurities. **Agronomy Journal**, v.95, p.293-302, 2003.

PROCHNOW, L.I.; CHIEN, S.H.; CARMONA, G.; HENAO, J. Greenhouse evaluation of phosphorus sources produced from a low-reactive Brazilian phosphate rock. **Agronomy Journal**, v.96, p.761-768, 2004.

RAIJ, B. van; ANDRADE, J.C.; CANTARELLA, H.; QUAGGIO, J.A. **Recomendações de adubação e calagem para o Estado de São Paulo.** Campinas: Instituto Agronômico, 1996. 285p.

RAIJ, B. van; ANDRADE, J.C.; CANTARELLA, H.; QUAGGIO, J.A. **Análise química para avaliação da fertilidade de solos tropicais.** Campinas: Instituto Agronômico, 2001. 285p.

SARRUGE, J.R.; HAAG, H.P. **Análises químicas em plantas**. Piracicaba: USP/ESALQ, 1974. 57 p.

SARRUGE, J.R. Soluções nutritivas. **Summa Phytopatologica**, v.1, p.231-233, 1975.

SAS INSTITUTE. **SAS/STAT user's guide;** version 6.11. 4.ed. Cary: SAS Institute, 1996, 842p.

VILLANUEVA, F.C.A; MURAOKA, T.; TREVIZAM, A.R.; FRANZINI, V.I.; ROCHA, A.P. Improving phosphorus availability from Patos phosphate rock for eucalyptus: a study with ^{32}P radiotracer. **Scientia Agricola**, v.63, p.65-69, 2006.

VOSE, P.B. **Introduction to nuclear techniques in agronomy plant biology**. London: Pergamon Press, 1980. 391p.

XIONG, L.M.; ZHOU, Z.G.; LU, R.K. Enhanced plant growth by uniform placement of superphosphate with rock phosphate in acidic soils. **Communications in Soil Science and Plant Analysis**, v.27, p.2837-2850, 1996.

ZAPATA, F.; ZAHARAH, A.R. Phosphorus availability from phosphate rock and sewage sludge as influence by the addition of water soluble phosphate fertilizer. **Nutrient Cycling in Agroecosystems**, v.63, p.43-48, 2002.

Received December 11, 2007
Accepted July 28, 2008